THE LOCAL AREA AUGMENTATION SYSTEM: AN AIRPORT SURVEILLANCE APPLICATION SUPPORTING THE FAA RUNWAY INCURSION REDUCTION PROGRAM DEMONSTRATION AT THE DALLAS/FORT WORTH INTERNATIONAL AIRPORT

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Abstract

The Federal Aviation Administration (FAA) created the Runway Incursion Reduction Program (RIRP) to reduce runway incursions throughout the National Airspace System (NAS) by increasing situational awareness, incursion monitoring, and information alerting for Air Traffic Controllers (ATC), pilots, and surface vehicle operators. A recent RIRP activity involved undertaking a technical evaluation and demonstration of a prototype system at the Dallas/Fort Worth International Airport (DFW). A Local Area Augmentation System (LAAS) was one of the major sensor subsystems included in this system.

As part of the RIRP team, the Ohio University Avionics Engineering Center (AEC) installed, operated, and tested the LAAS ground facility (LGF) at DFW. LAAS is a differential GPS-based precision approach and landing system that can be used to support surface operations. It is capable of providing sub meter position accuracy and consists of satellite, ground-based, and user subsystems. The ground subsystem includes multiple reference antennas, receiving equipment, processing software/hardware, and VHF Data Broadcast (VDB) equipment. The GPS signals received by multiple reference antennas are processed to obtain differential-correction and integrity information. The VDB equipment transmits the correction and integrity information to the airborne (or user) subsystem. The airborne subsystem uses the information obtained from the satellite and ground subsystems to calculate differentially corrected position estimates.

This paper will provide an overview of the RIRP system architecture and an introduction to LAAS. Also included are a discussion of the LGF site selection, detailed description of LGF , the test equipment used for performing accuracy and coverage assessments, and the data collection activities performed. Results of the testing and demonstration at DFW will be presented along with conclusion and recommendations, as appropriate.

Runway Incursion Reduction System – an Introduction

A runway incursion is defined by the FAA as, "*Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land"* [1]. An incursion can be one of four different types [1]. Pilot deviation is when the pilot makes a maneuver resulting in an expected deviation from a flight plan or course change without ATC notification. Vehicle or pedestrian deviation is similar to pilot deviation but rarely is there an expected change of plan. Operational error is the failure to comply with procedures governing the execution and performance of an operation. Operational deviation occurs when a separation minimum between an aircraft and protected airspace is not maintained or when an aircraft has penetrated airspace designated for another operation or facility without approval. Runway incursions have increased annually at a rate exceeding 14% from 1993 to 1997 [1,2]. The Federal Aviation Administration (FAA) established the Runway Incursion Reduction Program (RIRP) in an effort to prevent and reduce runway incursions. The goal of this program is two fold [1].

One part of the goal is to solve general system-wide problems and expedite implementation of workable solutions. The second part is focused on local projects and initiatives to solve airport specific runway incursion problems.

In 1999 and 2000 a RIRP technical evaluation and demonstration of a prototype system was conducted at Dallas/Fort Worth International Airport (DFW) [3]. As illustrated in Figure 1, this system consisted of the following major sensor subsystems: Airport Surface Detection Equipment (ASDE-3); Airport Target Identification System (ATIDS); Inductive Loops (LOT); Vehicle Automated Dependent Surveillance Broadcast (V ADS-B); and, Flight Planning Unit (FPU). Supporting components included: Surface Surveillance Data Server (SS); Local Area Augmentation System (LAAS); Data Link Manager; and, associated prototype and engineering displays.

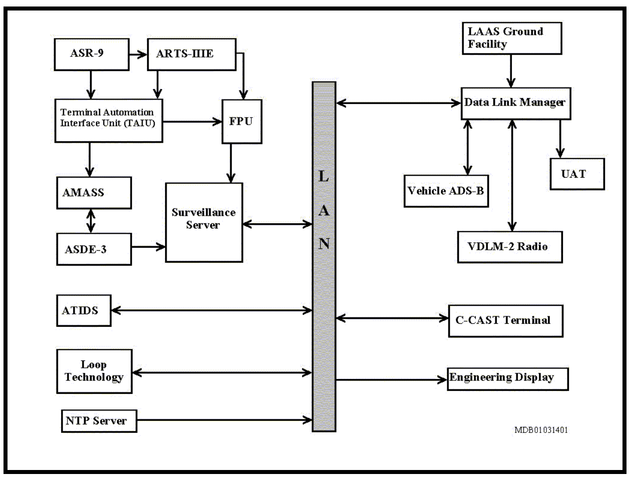

Figure 1. Prototype RIRP System Architecture.

GPS - Local Area Augmentation System (LAAS) Overview

The LAAS component of the RIRP was the responsibility of the Avionics Engineering Center (AEC) at Ohio University. LAAS is a differential GPS based (DGPS) precision approach and landing system; it may also be used to support airport surface operations. LAAS consists of three sub systems: the satellite subsystem produces ranging signals; the ground subsystem provides the VHF Data Broadcast (VDB) containing differential corrections and integrity information; and the airborne (or user) subsystem is the equipment used by the aircraft to process the LAAS corrections and compute a differentially-corrected position estimate. These subsystems are illustrated in Figure 2.

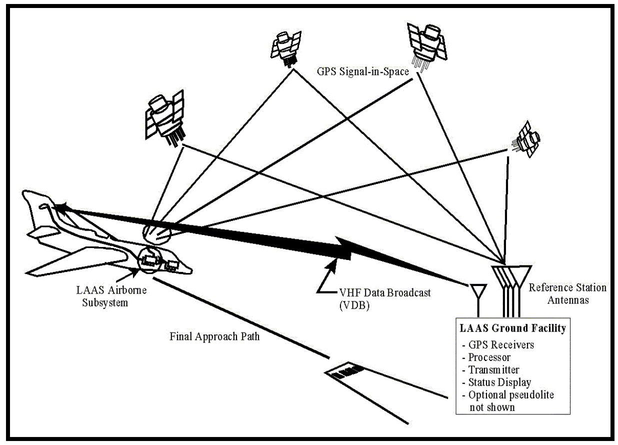

Figure 2. LAAS Satellite, Ground-based, and Airborne Components.

The ground subsystem includes multiple reference antennas, receiving equipment, processing software/hardware, and VHF Data Broadcast (VDB) equipment. The GPS signals received by multiple reference antennas are processed to obtain differential correction and integrity information. The VDB equipment transmits the correction and integrity information to the airborne (or user) subsystem. The airborne subsystem uses the information obtained from the GPS satellite constellation and the ground subsystems to calculate differentially corrected position estimates.

In the RIRP system at DFW, LAAS was used to provide differential corrections that enabled generation of very accurate DGPS position/velocity estimates. The data link equipment supports airborne and surface surveillance by broadcasting user position and identification.

RTCA DO-247 Surveillance and Guidance Sensor

The RTCA Document number 247 is a report on the Global Navigation Satellite System (GNSS) and its role in airport surface operations. The system architecture postulated in RTCA DO-247 focuses on the application of augmented GPS and ADS-B technologies for use in airport surface surveillance and guidance roles. For the surveillance function, augmented GPS can be utilized as the position sensor. The position information is then provided to the ADS-B equipment, and it is then broadcast along with user identification information to ATC and other equipped users. The LAAS was the form of augmented GPS used during DFW RIRP activities.

RTCA DO-247 contains requirements for the accuracy, integrity, continuity, and availability of the surveillance position sensor. FAA and RTCA activities have been underway for some time to address integrity, continuity, and availability requirements for LAAS in the case of precision approach operations, as well as the capability of candidate LAAS equipment architectures to meet these requirements. The vast majority of this work is expected to be applicable to the case of supporting airport surface operations.

Selection DFW LAAS Site

DFW was chosen as the RIRP evaluation site for several reasons. The most notable reasons are that DFW is a large airport with a complex layout, many major surveillance systems already exist on site, and there are a high number of aircraft operations each day (Figure 3). In addition, the program was endorsed strongly by local and regional personnel. The evaluation and demonstration activities were performed only on the east side of the airport, as originally planned. Accordingly, site surveys were performed to determine the location of the equipment and sensors needed to complete the RIRP system. This activity included the selection of a suitable site for the LGF.

During a site visit to DFW in April 1999, AEC personnel identified two candidate locations for installation of the LGF (Figure 3). One location was directly west of the east control tower and the other was west of the east RTR site. The site by the east tower was the preferred location in terms of access to electrical power, access to the site, and the availability of the RIRP office trailer for housing the LGF electronics cabinet. However, signal blockage and multipath from the east tower structure were of concern. These effects could yield some availability problems for the LAAS given the close proximity of the reference antennas to the east control tower.

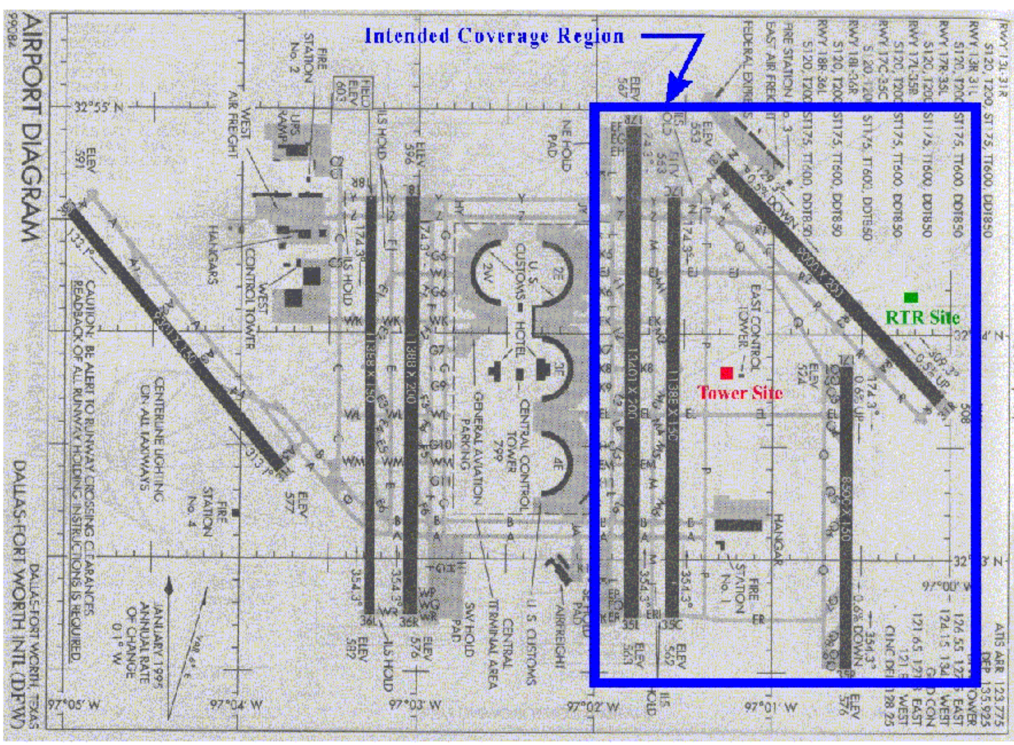

Figure 3. DFW Airport Layout, RIRP Coverage Region, and Candidate LGF Sites.

In July 1999, AEC personnel conducted a test to assess the feasibility of using the east tower site. This test involved setting up an AEC mobile LGF (similar to the configuration shown in Figure 5.) and collecting ground facility data for a 36-hour period. The raw data collected by the LGF were processed to generate an achieved ground accuracy curve, which is an estimate of the error on the differential corrections as a function of satellite elevation angle. The achieved ground accuracy curve can then be compared to the appropriate Ground Accuracy Designator Curve to assess the LGF performance. Such a comparison is provided in Figure 4. The results show that multipath from the east control tower does effect the LGF performance, as expected. However, the achieved ground accuracy curve, referred to as "Measured PRC Error Sigma" in Figure 4, is comparable to the Ground Accuracy Designator Curve for a Class A reference receiver. That is, the accuracy performance required to support Category I precision approach operations. The vertical accuracy performance required for Category I operations (4 meters) is more stringent than the DO-247 surveillance sensor horizontal requirement (8 meters) for the runway and taxiway regions [4,5]. Only the runway and taxiway regions are being considered for RIRP activities. Further, the surveillance sensor horizontal requirement for the gate region is 2 meters. Since the LAAS horizontal performance is typically 60 - 70 percent of the vertical performance, horizontal accuracy performance comparable the to 2-meter gate region requirement was expected. Thus, it was concluded that the accuracy performance needed to support RIRP activities could be achieved using the east tower location and a two-reference station LGF. Given this result, the assessment then focused on VDB coverage.

In conjunction with the ground facility data collection effort, an AEC test van was used to perform a preliminary surface coverage test to assess VDB coverage on the east side of the airport. The test involved recording the position of the test van using kinematic DGPS and the signal strength data output by a calibrated VDB receiver. The results show that the coverage should be sufficient to support RIRP activities. However, later testing revealed that assessment of signal strength alone may not be a sufficient means for assessing VDB coverage.

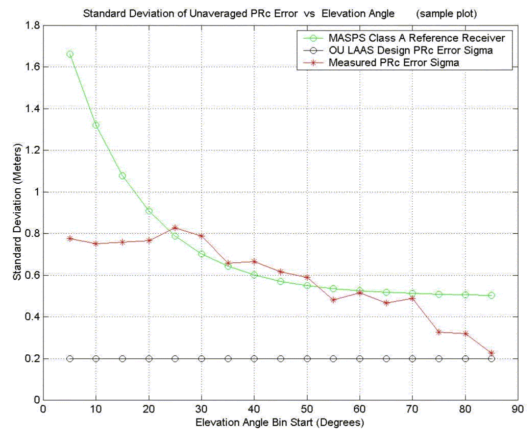

Figure 4. LGF Accuracy Performance Assessment

Based on the LGF performance assessment and VDB coverage test results, it was concluded that the performance necessary to support RIRP evaluation activities could be achieved using the east tower site. Efforts, at this point, focused on LGF installation activities.

Ohio University GPS LAAS Ground Facility Setup

AEC personnel supplied the material needed for the RIRP site coordinator to arrange a construction permit. Orders were placed with vendors for the procurement of the equipment necessary to construct the LGF based on the prototype LGF developed and installed by AEC personnel at the Ohio University Airport (UNI). Figure 5 presents an equipment diagram for the LGF as configured to support RIRP activities at DFW. The DFW LGF consisted of the following equipment: two integrated multipath-limiting antennas (IMLA); two dual-bank 12 channel GPS receivers; an industrial computer with AEC LGF software; display and keyboard; VDB transmitter; VDB transmit antenna; and various power converter, power conditioning, and synchronization equipment. Additional information on the LGF equipment is provided in Table 1.

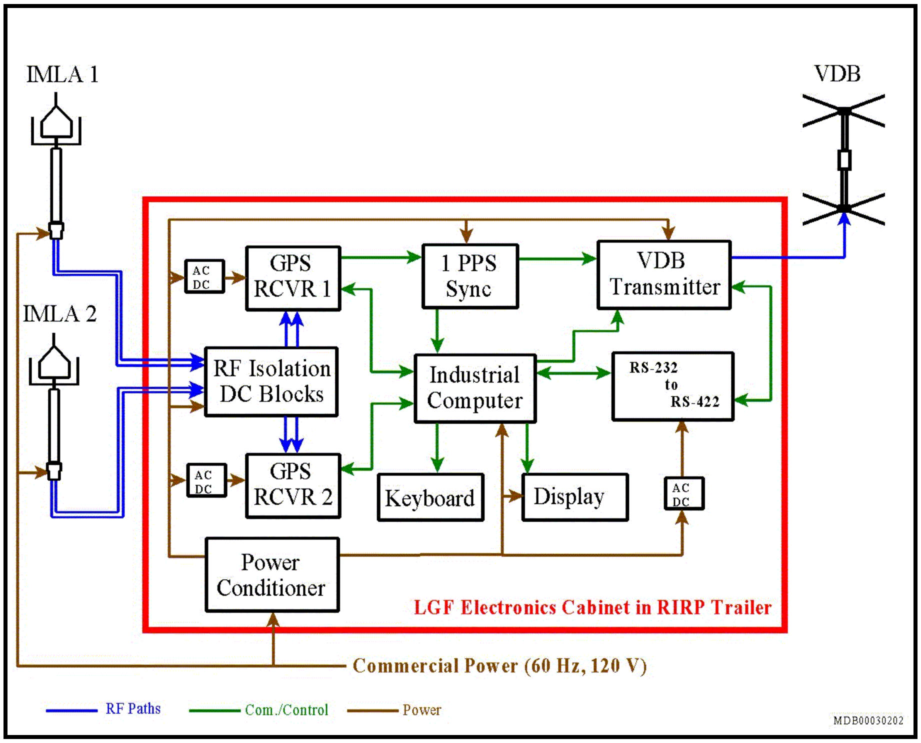

Figure 5. LGF Equipment Diagram.

Table 1. DFW LAAS Equipment Configuration Information.

ITEM	MANUFACTURER	MODEL
ILMA (2)	dBsystems, Inc.	dBs 200A-IMLA
VDB Transmit Antenna	Taco Communications	OFT-2M
GPS Receiver (2)	NovAtel	Propak-BeeLine
RF Isolation/DC Block Unit	Avionics Engineering Center	N/A
1 Pulse-per-second Box	Avionics Engineering Center	N/A
Industrial Computer	Ziatech	ZT-8908
VDB Transmitter	Harris Communications	VSR-2122
LGF Software	Avionics Engineering Center	

The DFW LGF equipment was completely assembled and tested at UNI prior to deployment of the system to DFW. The LGF was set up using an available temporary test facility located just to the south of the AEC hangar facility. The testing confirmed the proper operation of all hardware and software to be used at DFW with the exception of the IMLA antenna location data and VDB frequency assignment. These two items could not be completely tested at UNI, as the data is site specific.

The primary LGF elements installed at DFW included: two IMLAs, one VDB transmit antenna, and the LGF electronics cabinet. As shown in Figure 6, the two reference antennas were installed at locations “A” and “B”, and the VDB transmit antenna was located at point “C”. The electronics cabinet was housed in the RIRP office trailer, which was located inside the east tower security fence.

AEC contracted S&J Electric, Ft. Worth, Texas, for installation of the antenna mounts needed for the IMLAs and for the trenching/cabling required to run the RF and electric lines between the IMLA locations and the RIRP office trailer. The balance of the installation work was performed by AEC personnel. The installation work was completed in November 1999, and initial accuracy and coverage assessment performed on the east side of DFW confirmed that the LGF was operating properly. The IMLA installations are shown in Figure 7.

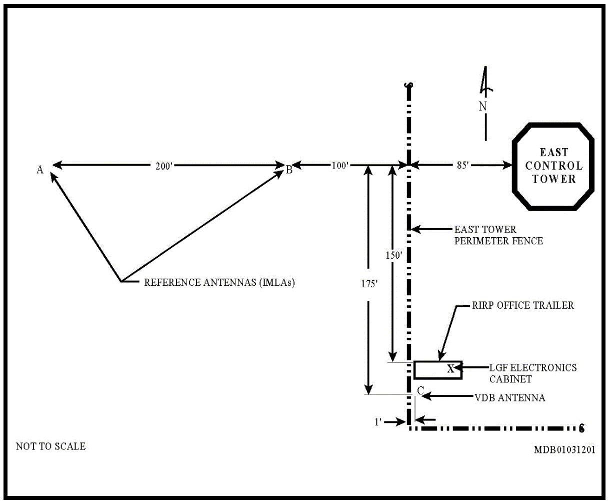

Figure 6. LGF Equipment Locations for DFW Installation.

Figure 7. IMLA Antenna

Ohio University GPS LAAS Test Van

In conjunction with RIRP test and evaluation activities, LAAS data collection activities were conducted during November 1999, December 1999, and May 2000. To evaluate the performance of the DFW LGF, an AEC test van with LAAS test equipment was used to support the data-collection work. The van was configured and calibrated prior to deployment to DFW. In addition, taxi and flight tests using an AEC Piper Saratoga with LAAS test equipment was performed during the May 2000 data collection activities. Data plots were generated to provide preliminary assessments of the accuracy and coverage performance.

The objective of the data collection work was to collect performance data along all runways, major taxiways, and in the gate area. Again, this work focused on the east side of DFW. The dotted line in Figure 8 shows the areas where measurements typically were made with the test van. Only on a rare occasion was a major taxiway excluded from the route and access to the gate area was authorized for the majority of the runs performed. All testing on the airport surface was conducted at night. The speed and direction along the route was varied during the testing, and slight changes to the route were made in accordance with air traffic control requirements. When surface and weather conditions permitted, several high-speed, (i.e., exceeding 87 kts.) runs were performed on Runways 35C and 35L, some which utilized high-speed exit maneuvers.

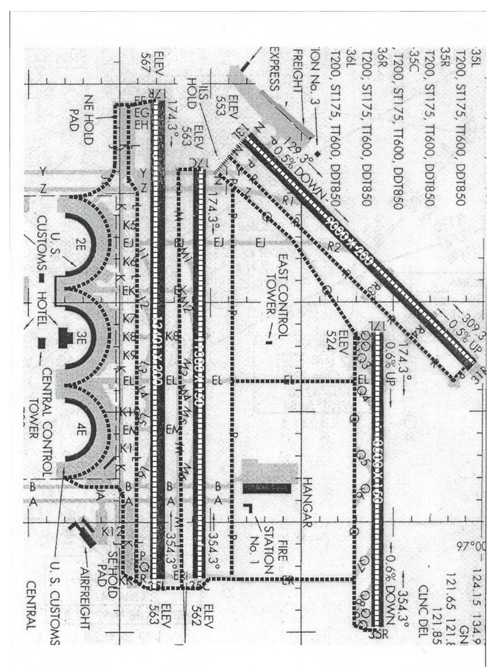

Figure 8. The East Side of DFW.

The van instrumentation included two NovAtel narrow correlater GPS receivers, a VDB receiver, and PC-104 based Pentium™ class computer (Figure 9). In addition to recording the raw data, the computer combined the raw measurements from the NovAtel receivers with the differential corrections from the VDB receiver to compute differentially-corrected position and velocity information. This information was generated at a 1 Hz rate for this test activity. Position, velocity, and status information were displayed in real-time during the tests.

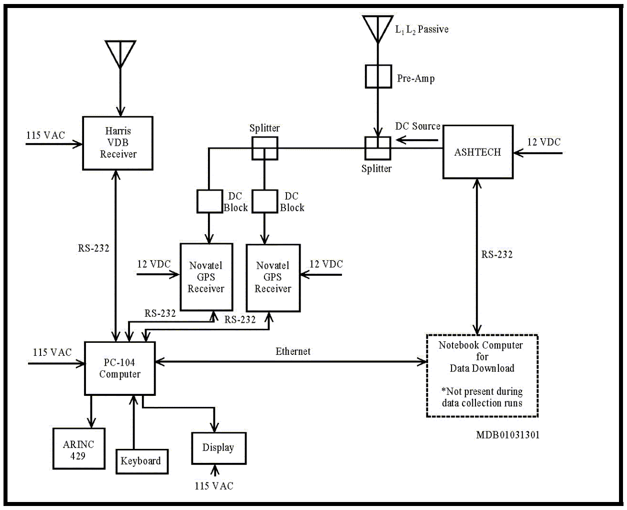

Figure 9. Airborne/User Equipment.

In addition to the aforementioned instrumentation, a high precision (i.e., centimeter level accuracy) GPS based kinematic survey system was used as a truth reference. The truth reference system consisted of two Ashtech Z-12 survey receivers. One receiver, the base unit, was located at a precisely surveyed control point near the LGF. The other, rover unit, was installed in the test van. The GPS antenna installed on the van was shared by the NovAtel and Ashtech GPS receivers. When the Piper Saratoga was used to support the testing, a third Ashtech receiver, or rover unit, was installed in a similar fashion.

During the tests, the truth reference data (Ashtech) and the LAAS data were collected simultaneously. For each, position data, as well as raw data, were recorded with GPS-based time tags. The truth reference data were collected directly by the Ashtech receivers. The PC-104 computer was used to record the NovAtel receiver data, the VDB link data, the VDB signal strength/status message output by the VDB receiver, and the LAAS generated differentially-corrected position.

The data from the Ashtech base unit and corresponding rover unit were processed using Ashtech PNAV software to compute the "true location" of the van, or aircraft, as a function of time. LAAS accuracy data was generated by subtracting the truth reference position (true location) from the LAAS position generated at the same instant in time. The resulting composite, time synchronized data records allowed for data plots to be generated as a function of run time (Figure 10) or geographical location on the airport surface (Figure 11). The existing data reduction software is capable of producing plots for position accuracy, VDB signal strength, and collective VDB message rate/interval.

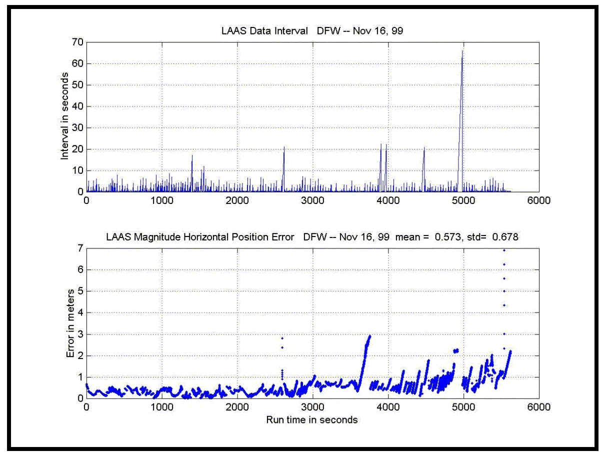

Figure 10. Example Plots, LAAS Data Interval and Horizontal Position Error Magnitude.

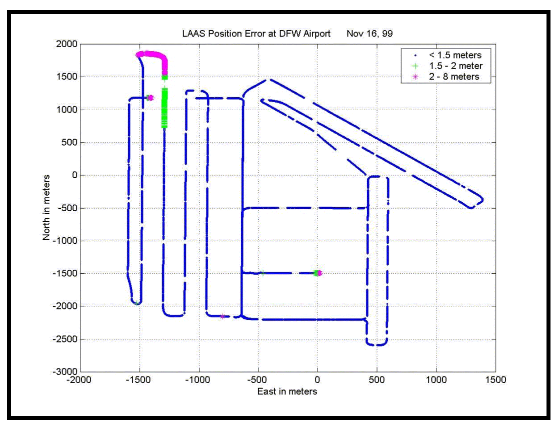

Figure 11. Example Plot LAAS Position Error.

Table 2. LAAS Van Test Results - Accuracy Performance.

Data Collection Dates	East Position Error Mean (m)	East Position Error Std (m)	North Position Mean Error (m)	North Position Std (m)	Horizontal Position Error Mean (m)	Horizontal Position Error Std (m)	95% Lateral Position Error (m)
16-Nov-99	-0.23	0.542	-0.157	0.407	0.278	0.678	1.63
17-Nov-99	0.027	0.319	0.074	0.324	0.079	0.455	0.98
6-Dec-99	-0.029	0.332	-0.131	0.296	0.134	0.445	1
7-Dec-99	-0.054	0.278	-0.175	0.295	0.183	0.405	0.98
8-May-00	0.291	0.545	0.014	0.562	0.292	0.783	1.79
9-May-00	0.257	0.538	-0.031	0.803	0.259	0.967	2.06
10-May-00	0.347	0.582	-0.101	0.73	0.361	0.934	2.03

Table 3. LAAS Van Test Results - VDB Performance.

Date	VDB Signal Strength Mean (dBm)	VDB Signal Strength Standard Deviation (dBm)
16-Nov-99	-74.6	9.5
17-Nov-99	-74.11	9.61
6-Dec-99	-72.7	10.14
7-Dec-99	-73.16	10.62
8-May-00	-74.26	9.25
9-May-00	-75.44	8.91
10-May-00	-74.7	11.8

Results

The analysis of the data focused on assessing the horizontal positional accuracy. To aid the interpretation of the accuracy results, VDB received-power data were generated and analyzed. There were four sets of data recorded in the year 1999, i.e., on November 16, 17, and December 6 and 7. In addition, there were three more sets of data recorded in the year 2000, i.e., on May 8, 9, and 10. The results of the analysis are provided in Tables 2 and 3. The east and north performance data were generated directly with the existing data reduction software. The horizontal performance data were estimated by a root-sum-square of the respective east and north performance data. The 95 percent lateral performance was estimated by finding the axis in the horizontal plane where the projection of the mean vector plus twice the projection of the standard-deviation vector was maximized. There is sufficient data to calculate the horizontal and lateral performance data directly, but to date this effort has not been undertaken. Similarly, further analysis of the link data would be required to generate message rate data for the various LAAS message types.

Conclusions and Recommendations

A two-reference station prototype LGF was sited, installed and tested successfully at DFW. The primary purpose of the installation was to support the Runway Incursion Reduction Program (RIRP) technical evaluation and demonstration activities. This effort represents the first time LAAS has been used to support surface surveillance operations at a major airport. In conjunction with RIRP activities, tests were conducted to verify the capability of

LAAS to meet the surveillance and guidance function sensor accuracy requirements contained in RTCA DO-247. It should be noted that the performance requirements contained in DO-247 are considered provisional and verification of the performance requirements has been recommended.

The performance data collected during surface accuracy and coverage tests performed on seven separate occasions showed that the 95 percent lateral performance ranged between 0.98 and 2.06 meters. This performance is well within the surveillance sensor requirement of 8 meters for runway and taxiway regions. Note, RIRP activities considered only the taxiway and runway regions on the east side of DFW. On two of the seven occasions, the performance marginally exceeded the 2 meter surveillance sensor requirement for the gate region. Although the 95 percent performance data show performance on the order of 1 - 2 meters, the plots of accuracy as a function of geographical location show operationally significant areas where 6 - 8 meters would be a more representative estimate of the performance. This situation would need to be addressed in the case where LAAS was to support airport surface guidance operations.

It should be noted that improved accuracy can be obtained through the use of additional ground reference stations. Only two IMLA antennas were employed for these tests based in the need to support only the 8 meter requirement and the need to reduce the cost of the installation. Also, although the east tower location proved to be an acceptable location for supporting surface surveillance activities, it is not the best location available at DFW for siting a LGF as previously noted. It was selected based on access to AC power, access to the site, and availability of the RIRP office trailer to house the LGF electronics. In addition, this site provided the opportunity to collect data that would aid the development of LGF siting criteria, which is necessary for successful implementation of LAAS within the U.S. National Air Space System.

The VDB coverage and link data analysis were very limited. Although the performance statistics generated for the VDB signal strength data show acceptable performance was achieved, coverage plots show link outages in operationally significant areas. The relatively low-power (20 w) transmitter used for these tests combined with about 3 dB line loss due to the long antenna cable running between the transmitter and antenna likely contributed to many of the coverage holes observed. In addition, investigation of the test van revealed a 12-14 dB notch in the VDB antenna pattern in the direction of the driver side, rear corner, which likely caused some of the coverage holes observed. In addition, real-time observations made by the data-collection personnel, during data-collection runs, indicated that some holes in the coverage existed at locations where the signal strength was at acceptable levels. Corruption of the message content by multipath is a possible cause in this case. Finally, siting of the VDB antenna was based on best engineering judgement, as formal siting criteria for the VDB antenna remains to be developed and validated. Again, the data collected can be used, in part, to support such efforts.

Based on the 95 percent performance data and the above considerations, the following has been concluded:

- The LGF reference receiver and VDB transmit antennas must be sited at suitable locations to ensure that required accuracy and coverage performance are achieved;
- A properly sited, Performance Type I LAAS should be capable of meeting the RTCA DO-247 surveillance sensor accuracy requirements for runway and taxiway regions;
- A properly sited, Performance Type II/III LAAS should be capable of meeting the RTCA DO-247 surveillance sensor accuracy requirements for the gate region;
- A properly sited, Performance Type II/III LAAS should be capable of meeting the RTCA DO-247 guidance sensor accuracy requirements for visibility conditions *1* (10 m), *2* (10 m), and *3* (2.2 m);
- Additional analysis of the existing performance data is required before a conclusion can be offered regarding the capability of LAAS to meet the guidance sensor accuracy requirement for visibility condition *4* (1.5 m);
- Additional tests should be conducted to verify the capability of LAAS to meet DO-247

sensor requirements under different siting and environmental conditions; and,

- The tests conducted were not suitable for validation of the DO-247 accuracy performance requirements.

The following recommendations are offered:

- Tests suitable for validation of the DO-247 performance requirements should be conducted;
- Although generating the 95 percent performance data is useful as an initial assessment, more operationally relevant assessment methodologies should be developed;
- Additional data reduction and analysis work should be conducted to assess the VDB performance achieved during RIRP activities at DFW;
- Additional data reduction and analysis work should be conducted to better assess and characterize the LAAS accuracy performance achieved at DFW, especially locations where the position error exceeded 2 meters. These situations should be analyzed to determine if the cause is multipath at the LGF location, multipath at the user location, and/or VDB coverage;
- Siting criteria for the LGF reference stations and VDB transmit antenna should continue to be developed, refined, and validated;
- Additional reference stations should be installed prior to conducting research intended to assess the capability of LAAS to support airport surface guidance, especially for visibility condition 4 requirements;
- Future testing should be conducted using a VDB transmitter with a power rating more representative of the equipment likely to be fielded;

References

1 Mead, Kenneth M., "Federal Aviation Administration's Runway Incursion Program", Statement before Subcommittee on Aviation, Committee on Transportation and Infrastructure, U.S. House of Representatives, November 13, 1997.

2 Federal Aviation Administration Runway Incursion Reduction Program Website, http://www.faa.gov/faa_office/rirp/index.htm.

3 Runway Incursion Reduction Program Test and Evaluation Master Plan (TEMP) for Demonstration and Validation Activities at Dallas/Fort Worth International Airport (DFW), RIRP-DFW-026-A, Revision 2.3, Volpe National Transportation Systems Center, Airport Surface Division, DTS-54, Cambridge, MA, November 10, 1999.

4 Minimum Aviation Performance Standards for the Local Area Augmentation System (LAAS), Requirements and Technical Concepts for Aviation (RTCA), Document No. RTCA/DO-245, September 28, 1998.

5 The Role of the Global Navigation Satellite System (GNSS) in Supporting Airport Surface Operations, Requirements and Technical Concepts for Aviation (RTCA), Document No. RTCA/DO-245, January 7, 1999.